Ecosystem Dynamics and Succession after Tundra Fire, Yukon-Kuskokwim Delta

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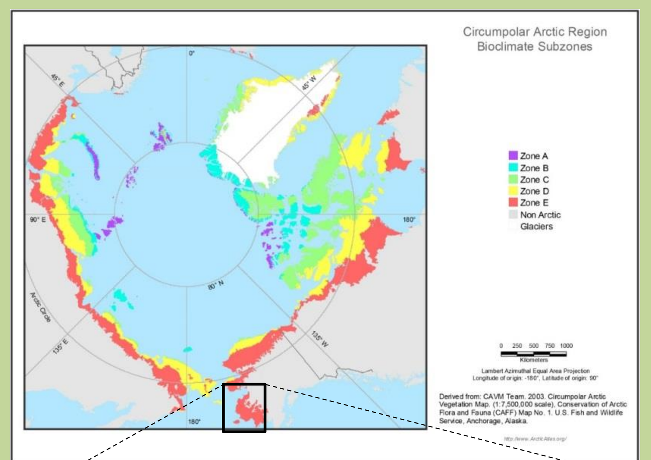
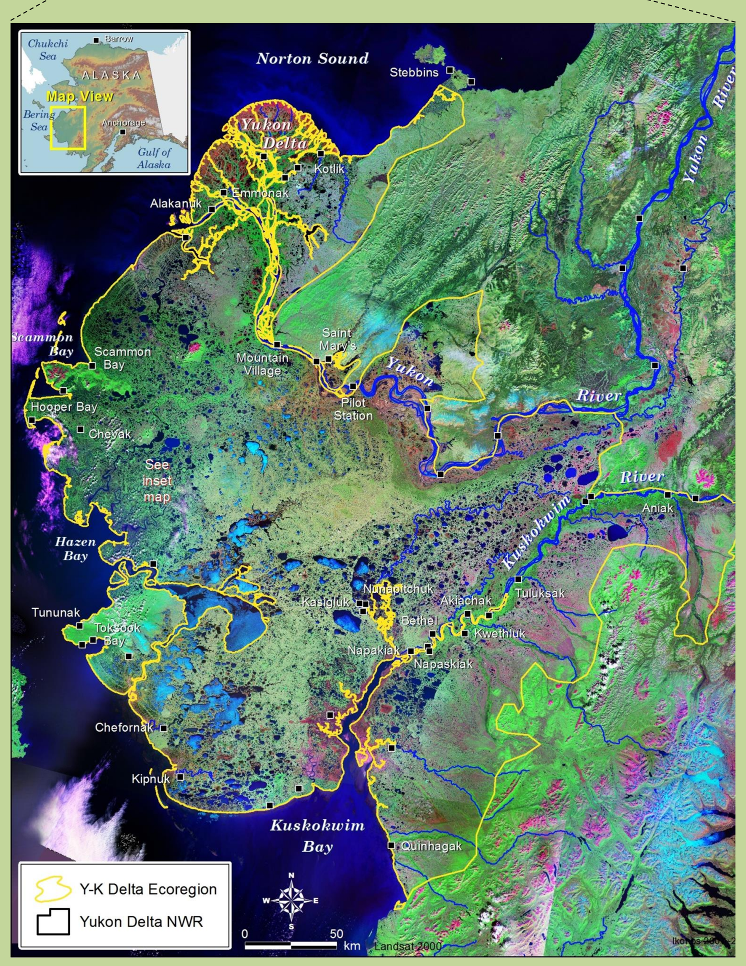
Abstract

The Yukon-Kuskokwim Delta (YKD) encompasses the southernmost, warmest parts of the arctic tundra biome. Ice-rich permafrost currently is widespread and strongly influences terrestrial and aquatic environments. In 2015, the YKD experienced large wildfires across >1,200 km² of permafrost-affected upland tundra. Although the 2015 fire season was exceptional, tundra fire is common in this region with episodes of historical fire circa 2005, 1985, and 1971, offering a natural laboratory for understanding the ecosystem impacts of tundra fire in a discontinuous permafrost region during a period of warming air and ground temperatures. In 2017, we collected field data on vegetation, soils, and burn severity within recent and historical burns and unburned tundra. Using these data we analyzed patterns of correspondence between vegetation species-composition and structure, soil properties, and fire history. We also tested for differences in biophysical properties among the tundra fire epochs and unburned tundra. Vegetation in unburned tundra was dominated by lichens, whereas burned areas support enhanced cover of shrubs and mosses; however, post-fire shrub cover was composed of the same low-statured species common to unburned tundra and we seldom observed sites colonized by taller, canopy-forming species. Geomorphology and soils were similar in burned and unburned tundra, likely because thick peat layers protected ice-rich permafrost and conferred ecosystem resilience after fire. While this historical perspective suggests that peaty soils will moderate the impact of the 2015 fires, we did observe secondary impacts related to permafrost degradation in circa 2005 fires that were not evident in older burns, such as thaw-settlement, increased surface wetness, complex microtopography, and progressive mortality of shrubs. These contrasts represent persistent, rather than successional shifts and suggest that upland ecosystems of the YKD may be less resilient to wildfire disturbance than they were in the past.

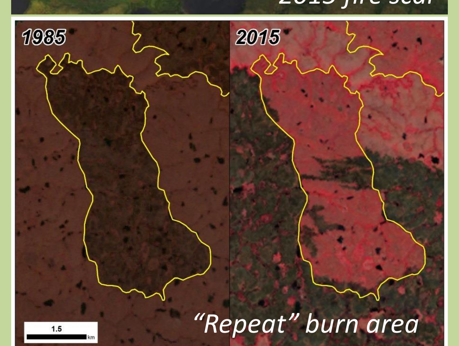
Background



- southernmost part of tundra biome
- MAAT approx. -2° C
- extensive "warm" permafrost
- ~150 known tundra fires since c. 1953
- 35 villages
- ~30,000 Yup'ik people
- exceptional breeding habitat for waterbirds




2015 fire scar

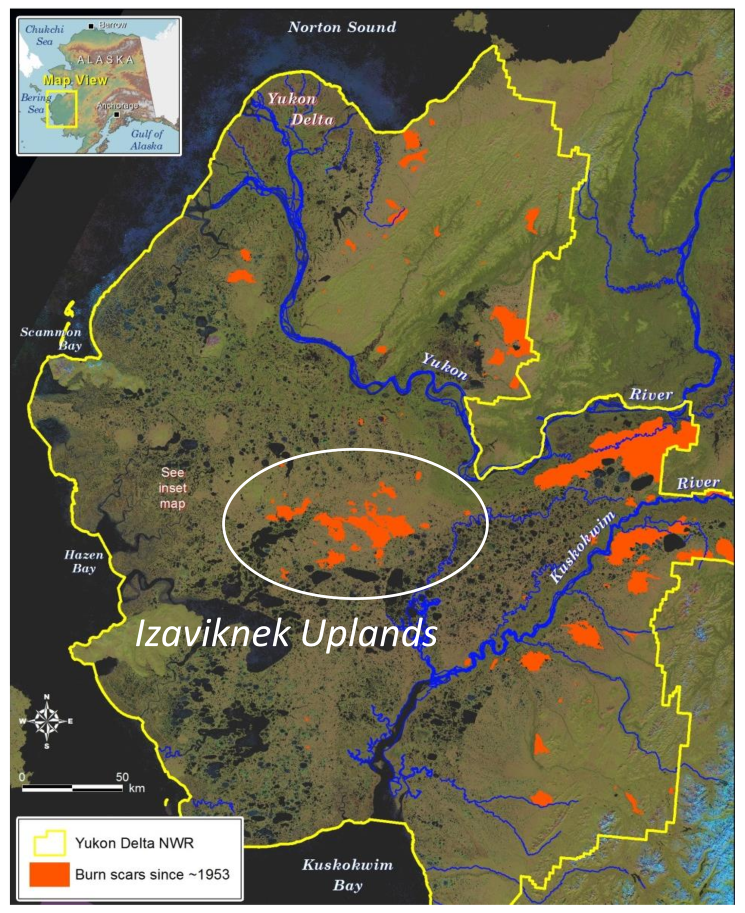


"Repeat" burn area

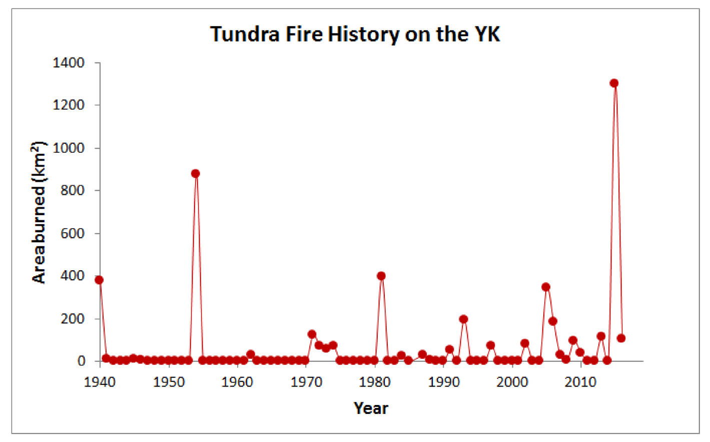

Kasigluk village

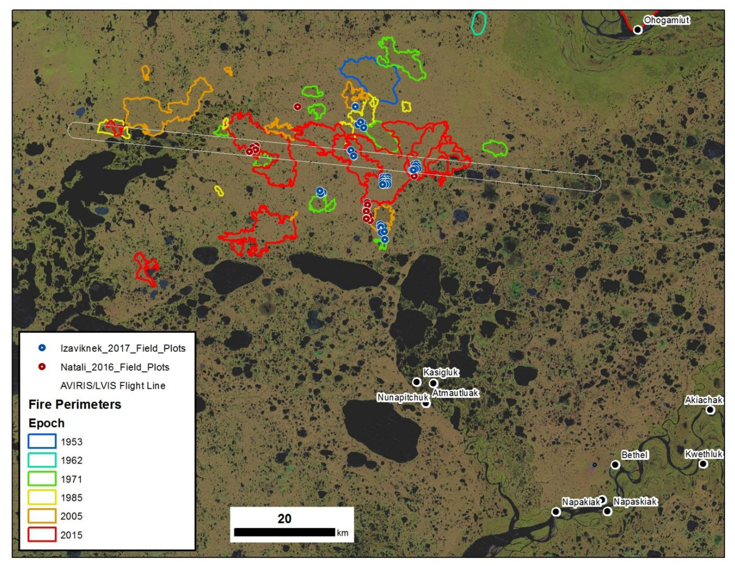
- Y-K Delta has been underrepresented in studies of arctic environmental change despite high societal value
- Pleistocene eolian deposits overlie older portions of the delta and form extensive upland regions with ice-rich permafrost
- uplands of the YK Delta have one of the most active tundra fire regimes in the Arctic

What is the Fire History of the YK?

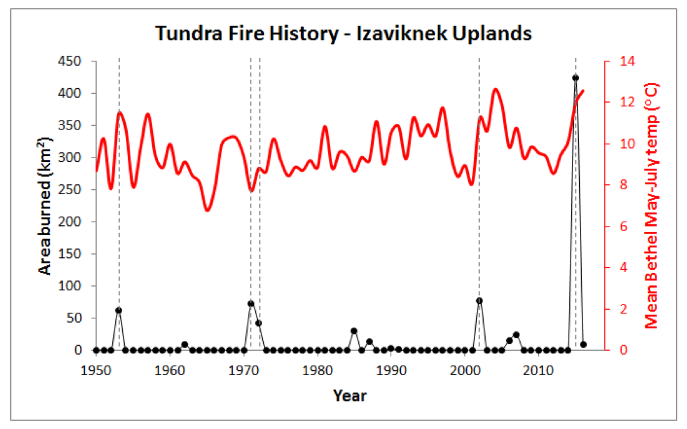


The YKD is best known for its flat, deltaic wetland landscapes. But, uplands are widespread and the region has one of the Arctic's most active fire regimes. The 2015 fire season was exceptional especially in the Izaviknek Uplands northwest of Bethel. However, tundra fires were also common in the early 1950s, early 1970s, early 1980s, early 1990s, and mid 2000s. Many basic aspects of the YKD's fire regime are poorly understood—for example, wildfires from 1985–1999 are poorly documented because virtually no Landsat data were acquired during this period.

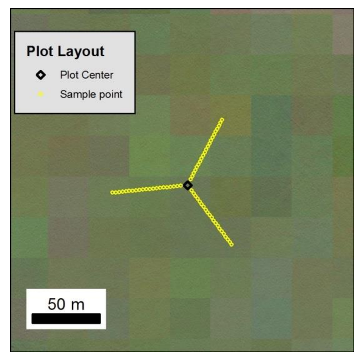


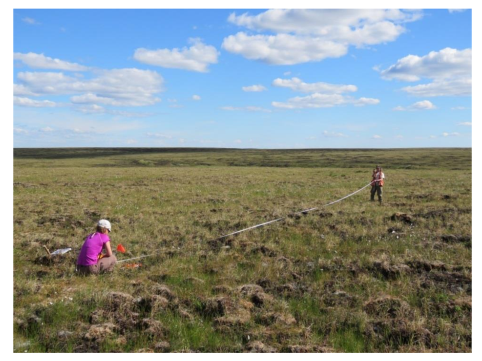


(left) A large proportion of the Izaviknek Uplands have burned within the last 60 years. In 2017 we sampled 25 plots in burned and unburned areas. **(below)** Fire events tend to occur after warm, dry springs.

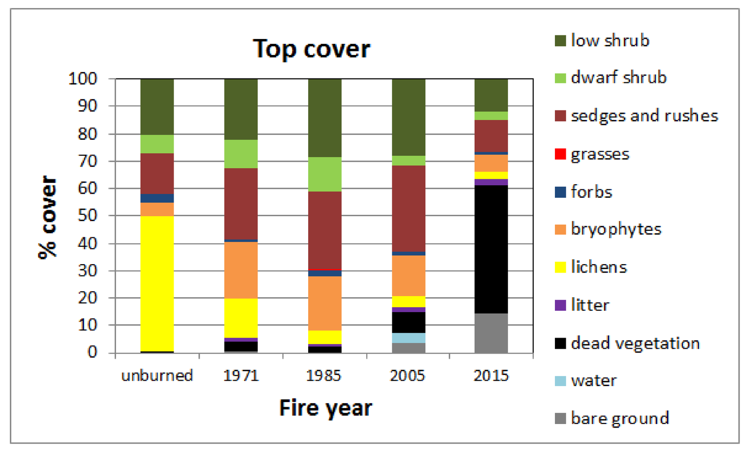


Vegetation Sampling

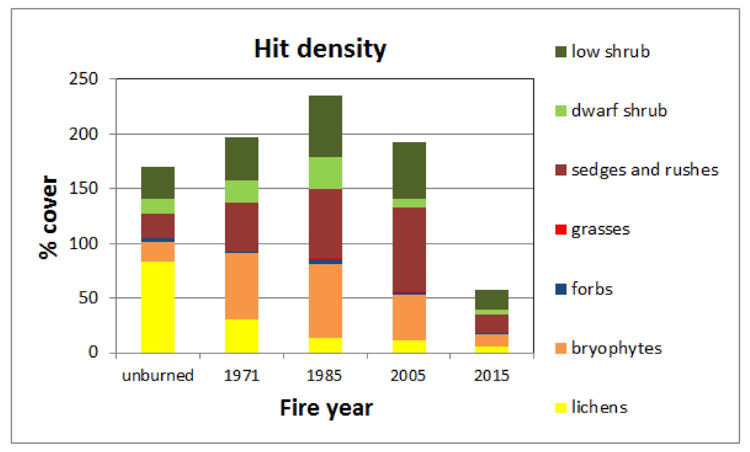




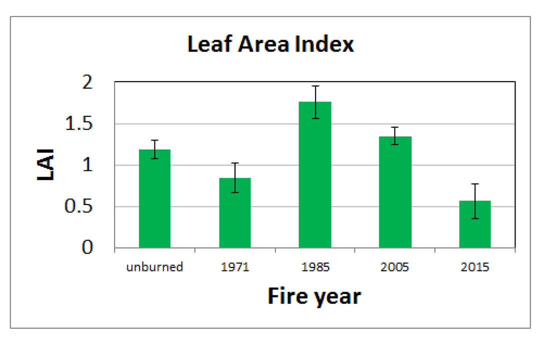
The short-term effects of fire on tundra vegetation are well understood – but what about long-term impacts? The Izaviknek Hills region is an ideal study area to address this question because species-composition and ecological state-factors are homogeneous across the region. We sampled vegetation in unburned tundra, and tundra that burned circa 1971, 1985, 2005, and 2015. Each plot consisted of 3 50-m transects. We recorded vegetation and abiotic ground cover types at 1-m intervals using a point-intercept approach and summarized by plant functional type. These training data will also be related to UAV imagery and scaled to Landsat seasonal composites and used to predict the cover of plant functional types across fire-prone uplands of the YKD. We also measured Leaf Area Index (LAI), shrub height, and ecological site-factors.

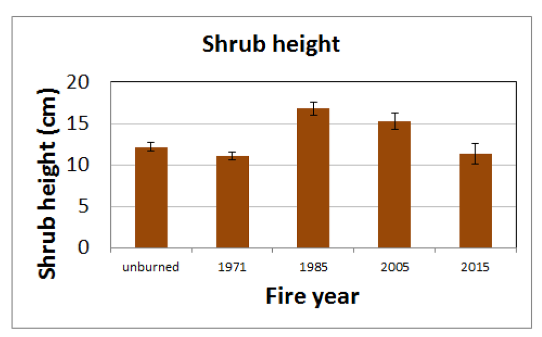


Top Cover is calculated from the first "hit" recorded during point-intercept sampling and represents the uppermost vegetation canopy or—in cases where there is no upright vegetation—the ground surface; this metric sums to 100%. Unburned tundra is distinctive because of the high cover of ground lichens. Most lichens die after fire and recover slowly; a higher proportion of shrubs, graminoids, and mosses survive fire and recover faster. Shrub cover peaked in the 1985 burn areas; lower cover in 1971 burns may be partly due to soil paludification related to *Sphagnum* growth.



Hit density is calculated using all "hits" recorded during point-intercept sampling (live vegetation only). It accounts for multi-layered plant canopies formed by shrubs and graminoids; this metric can exceed 100%. Unburned tundra is distinctive because of the high cover of ground lichens. Results from 2005 burns indicate a rapid, dramatic increase in sedge cover. Shrub increase appears to lag that of sedges. Over time, mosses and lichens make up a larger proportion of the live vegetation. This shift is accompanied by decreases in thaw-depth (see top right).



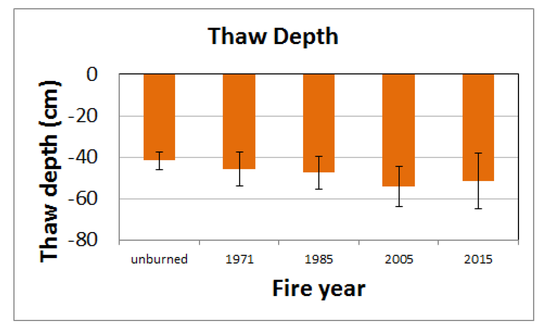


Western Alaska LCC

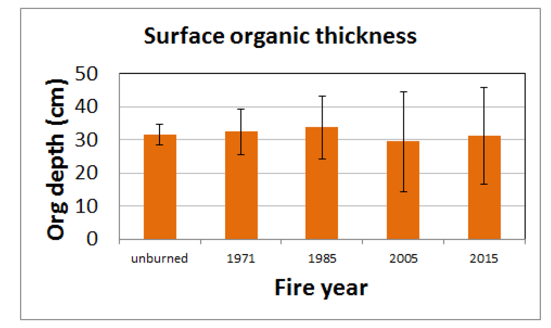
LAI (left) was highest in the 2005 and 1985 burns, but surprisingly low in the 1971 burns, where much of the vegetation consisted of *Sphagnum* moss that did not project above the LAI sensor. Unburned plots had thick lichen mats and some of the lichen projected above the LAI sensor. **Shrub height (right)** did not range very widely. Shrub cover was dominated by ericaceous shrub species; we seldom observed cases where taller species (e.g., willows) colonized burn areas.

ABoVE – ARCTIC – BOREAL VULNERABILITY EXPERIMENT

Soil Properties and Thaw Depth



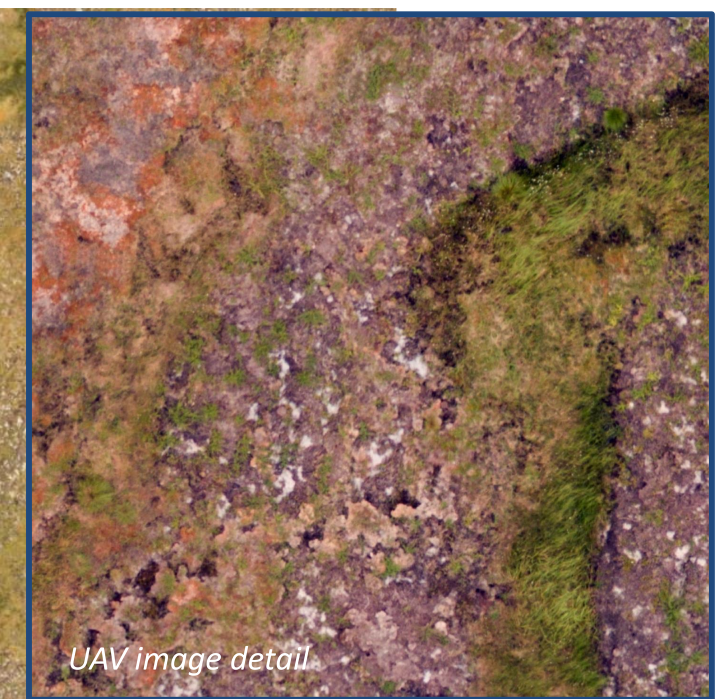
Thaw depth measured at the end off July was deepest in the 2015 and 2005 burns, intermediate in 1985 and 1971 burns, and shallowest in unburned tundra. However, the overall range of values is rather small and all treatments had thick accumulations of surface peat.

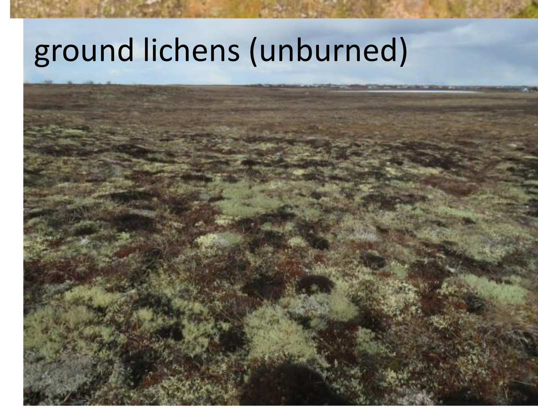


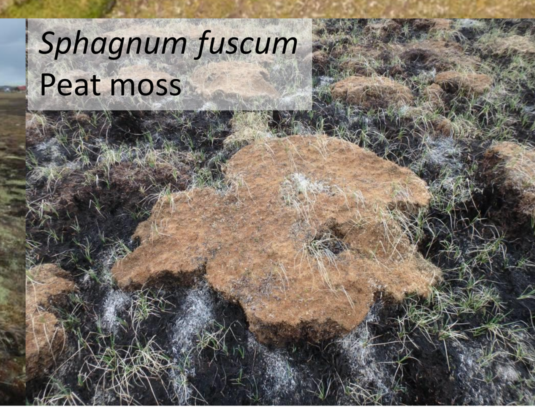
Surface organic thickness was remarkably consistent in burned and unburned areas. Although there was much microsite variability, we never observed sites where the organic layer was removed completely.

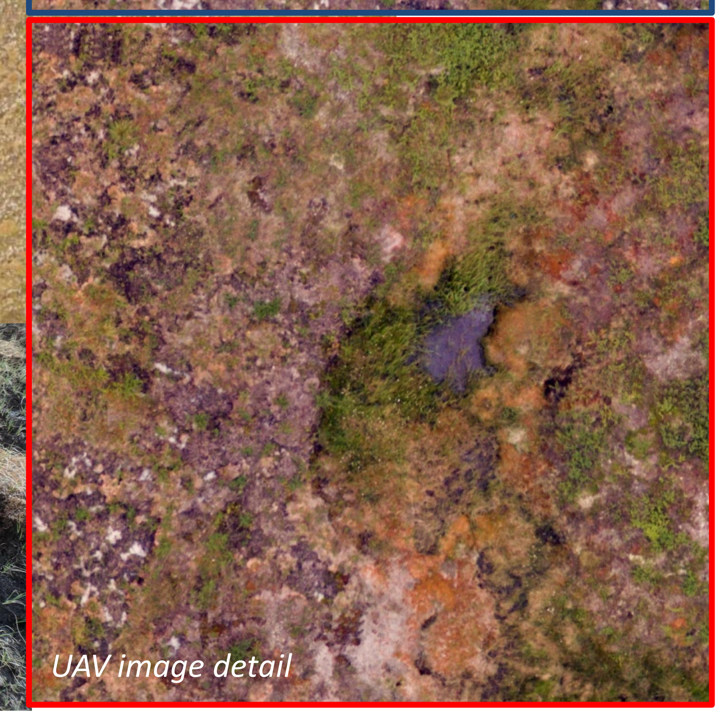
UAV Imaging


RGB photo mosaic of 2015 burn


UAV image detail


ground lichens (unburned)


Sphagnum fuscum Peat moss


UAV image detail

UAV imaging using a Phantom-4 Pro. UAV imaging provides a quick, efficient means of acquiring high-resolution imagery co-located with field measurements in most weather conditions. The imagery possesses sufficient detail to resolve plant functional types and even individual species. UAV data provides a crucial "middle" scale between field point-intercept data and the 30-m Landsat imagery that will be used to model the cover of plant functional types across the Izaviknek Uplands. Patterns of correspondence between abrupt shifts in plant functional type abundance, and known fire perimeters will help to corroborate the findings from the limited number of field plots. We also plan to survey breeding bird populations in the Izaviknek Uplands to assess habitat-use in various successional stages after fire.

Key Points

- We studied vegetation, soil, and permafrost properties in recent (2015) and historical tundra fire areas (1971, 1985, 2005)
- Short-term impacts of tundra fire are well understood, but longer-term impacts are not
- Thick layers of Holocene peat promote resilience to vegetation and "ecosystem-protected" permafrost and reduce the potential for colonization by early successional species
- In the decades after fire, there is a large increase in shrub productivity, but this is not necessarily sustained over time because successional processes favor soil paludification
- Surprisingly, thaw-depths in unburned lichen-rich tundra were shallower than in thick *Sphagnum* beds; the thermal properties of lichen beds warrant further study
- Unlike older burns, 2005 fire areas are experiencing extensive surface subsidence and shrub mortality, suggesting this ecosystem may be less resilient to fire than in the past

Acknowledgments

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